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SINGLE-BATH HOT-WATER AND STEAM TREATMENTS OF SEED WHEAT FOR THE CONTROL OF LOOSE SMUT

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INTRODUCTION

Loose smut, caused by the fungus *Ustilago tritici* (Pers.) Jens., is one of the commonly known destructive diseases of wheat. Recommendations for its control in this country have been confined almost entirely to treatment of the seed by the modified hot-water method. In general, this treatment is carried out as follows: A small quantity of seed wheat in a porous container is (1) presoaked for four to six hours in unheated water, (2) dipped momentarily in water heated to about 49° C., (3) immersed for 10 minutes in water maintained at 54° C., and (4) either dipped in cold water or spread out in a thin layer without dipping.

There is no doubt that the modified treatment completely controls loose smut (*4, 5, 13, 15*),[2] but reports from numerous sources show that it is practiced only to a limited extent, largely because the modified treatment is (1) relatively complicated and tedious for the individual farmer to apply, (2) it soaks the seed and this often leads to post-

[1] The writer makes grateful acknowledgment to W. H. Tisdale, C. R. Ball, and H. B. Humphrey for helpful criticisms of the manuscript, to N. C. Ellis for the drier used in the experiments with steam treatments, and to the agronomists in the wheat projects of the Office of Cereal Investigations and R. G. East, D. D. Ball, and M. E. Cromer, county agricultural agents in Indiana, for supplying the seed samples used in the experiments.

[2] Serial numbers (*italic*) in parentheses refer to "Literature cited," at the end of this bulletin.

treatment difficulties in handling and sowing the grain, and (3) it severely injures or kills the germination of seeds with broken coats (*15*), and the percentage of broken seed coats in machine-threshed wheat frequently runs high (*7*, *15*).

The experience gained abroad and in this country seems to show that in communities where loose smut in wheat is a factor of considerable economic importance a solution of the problem of application lies in the establishment of cooperative or community plants for seed treatment. According to Mercer (*11*) and others, the modified hot-water treatment has been used so extensively in cooperative dairies in Denmark that the disease is now said to be practically exterminated. In this country, in the State of Indiana particularly, as shown by Pipal (*13*) and Gregory (*5*), the modified treatment has received a big impetus since 1918, the year in which the first community plant in that State began operations.

The investigations reported here were therefore conducted to study and devise, if possible, a practical method or methods (1) yielding effective control but less injurious to germination, or (2) whereby the seed could be dried with facility after treatment, or both.

The methods studied were: (1) Treatments in which the seed in a porous container was simply immersed in a single bath of water maintained at a constant temperature. This is called the "single-bath" [3] method in the following pages. According to Humphrey and Potter (*6*) it is less injurious to germination than the modified method. (2) Steam treatments. The seed was first presoaked, then steamed in a commercial grain drier.

Attention is called to the fact that the single-bath and steam treatments were studied only from the viewpoint of application at cooperative or community seed-treatment plants. Their application involves the maintenance of constant temperatures for relatively long periods and other factors which make them hardly practicable of application by the individual farmer.

SINGLE-BATH HOT-WATER TREATMENTS

PREVIOUS INVESTIGATIONS

Experiments on the use of single-bath hot-water treatments for controlling loose smut of wheat or barley, or both, have been reported by a number of investigators. A comprehensive review is given by Appel and Riehm (*1*) of the various means employed by different investigators to control these diseases, including the single-bath treatment and other modifications of the hot-water method devised by Jensen (*8*). More recently Humphrey and Potter (*6*) have studied further the limitations of temperature and duration of treatment within which control may be satisfactorily effected by this method.

With barley satisfactory control frequently has been reported from treatment of the seed for two hours at 45° C. With wheat, however, satisfactory control evidently was less often obtained. The temperatures and durations of treatment used vary widely. Humphrey and Potter (*6*) recommend a three-hour immersion at 113° F. (45° C.)

[3] Referred to as the "Dauerbad" by Appel and Riehm (*1*) and the "long hot-water" or "Pasteurization" method by Humphrey and Potter (*6*).

for both wheat and barley, stating also that it has been found entirely feasible to vary the temperature at will between 105° and 120° F. (40.55° to 48.88° C.), provided the duration of treatment is varied accordingly within a range of one and a half to six hours. No specific recommendations are made regarding the duration of treatment within the limits of temperature defined, except the one noted above. Since it is desirable to make the treatments as short as possible, the shortest duration of treatment (one and one-half hours) and a temperature (48° C.) close to the highest recommended by Humphrey and Potter (*6*) were used as a starting point in the experiments with single-bath treatments, descriptions of which follow.

For a number of years previous to the beginning of the investigations reported here the Office of Cereal Investigations conducted experiments on the single-bath hot-water treatments for the control of the loose smuts in wheat and barley in cooperation with the agricultural experiment stations of Minnesota and Wisconsin. A. A. Potter had charge of the work at Washington, while the work in Minnesota was conducted by E. C. Stakman and that in Wisconsin was under the supervision of A. G. Johnson. The results of these earlier investigations are unpublished, but they have been made available for study by the writer, who is grateful to these workers and the officials of the experiment stations concerned for the use of the data. The writer is further indebted to Mr. Potter for suggestions regarding certain temperatures that should be given special consideration.

METHODS AND MATERIALS

Unless otherwise noted in the following experiments dealing with hot water, the seed was treated in cheesecloth bags with ample room to allow for the swelling of the grain. The 60-gallon tank used for treatment was equipped with two motor-driven propellers, which kept the water thoroughly agitated and the temperature uniformly distributed. Thermostatically controlled electric heaters were employed to maintain the desired temperatures, which were held in all cases with a plus or minus variation not in excess of 0.2° C. All of the thermometers employed had been standardized by the United States Bureau of Standards.

The single-bath treatments were applied without presoaking. The modified treatment was applied by presoaking the grain for four to five hours in cold water, followed by a momentary tempering dip in water at about 49° C. and a 10-minute immersion in water at 54° C. Immediately after treatment the seed was spread in a thin layer to cool. In order to reduce its moisture content to about that of the untreated seed, it was left to dry for five days or more at room temperature. Germination tests in the greenhouse soil were made by sowing 100 seeds per flat in flats 1 foot wide by 2 feet long. Uniform spacing and depth of sowing were insured by pressing into the soil one hundred 1-inch pegs inserted equidistantly in a board. The kernels were dropped into the holes made by these pegs and then covered.

EFFECTS OF SINGLE-BATH HOT-WATER TREATMENTS IN 1920–21

GERMINATION

In the first germination test six lots of Goens [4] and one lot each of Fultz (C. I. 1923),[5] Poole (C. I. 3489), and Stoner (C. I. 2980) wheat were used. These wheats were grown in 1920. Samples of each of the lots were treated on September 10, 1920, in single baths at different temperatures and for different lengths of time, as noted in Table 1. Samples of the same lots also were treated by the modified hot-water method for comparison. The treated seed was left to dry for 10 days at room temperature. After drying, 200 untreated seeds and 200 seeds from each of the treatments in each of the nine lots were sown in moist blotters and incubated at 19° C. Germination counts were made on the third, fifth, seventh, ninth, and eleventh days. The germination of many of the treated seeds, while apparently normal in appearance, was retarded in varying degrees. In some instances the seeds required the full period of 11 days to reach the stage commonly attained on the third and fifth days by the untreated wheat.

TABLE 1.—*Percentages of germination of seed of nine lots of wheat untreated or treated with hot water, as specified, and sown in blotters in the laboratory on September 20, 1920*

Treatment of the seed			Percentage of germination									
Kind and temperature	Duration		Lot 1, Goens	Lot 2, Goens	Lot 4, Goens	Lot 6, Goens	Lot 8, Poole	Lot 9, Stoner	Lot 10, Fultz	Lot 11, Goens	Lot 14, Goens	Average
	Hours	Minutes										
Untreated			94.0	87.5	91.5	95.0	93.5	92.0	82.0	82.5	94.0	90.22
Modified method			71.0	85.5	84.0	75.5	91.5	91.5	61.5	73.0	77.0	78.94
Single-bath method:												
At 48° C	1	30	95.0	94.0	86.0	82.0	93.5	88.5	61.5	74.5	85.0	84.44
	2		96.5	94.5	85.0	76.5	84.5	87.5	68.0	67.0	78.0	81.94
	2	30	92.0	90.5	80.5	82.0	85.5	84.0	60.0	51.0	79.5	78.33
At 49° C	1		93.0	93.5	86.0	91.0	90.5	93.5	71.5	66.0	87.5	85.83
	1	30	85.5	90.0	82.5	86.0	92.0	91.0	62.0	65.5	84.0	82.06
	2		76.5	86.0	75.0	73.0	85.5	81.0	61.5	48.0	84.0	74.50
At 50° C		45	91.0	94.5	87.0	84.5	95.5	88.5	66.5	79.0	85.0	85.72
	1		94.5	88.0	74.5	89.0	87.0	89.0	63.0	58.5	85.5	81.00
	1	15	89.5	90.5	62.0	83.0	87.5	82.5	45.5	71.5	83.0	77.22
At 51° C		30	92.0	93.5	86.0	89.5	89.5	89.0	67.5	70.0	83.5	84.50
		45	93.0	95.0	85.5	88.0	88.5	89.0	57.5	68.0	86.0	83.39
	1		71.0	91.5	74.5	81.5	91.0	86.0	52.0	57.0	77.0	75.72

Table 1 shows that the seed was injured most by the modified method and by the longest treatment at each of the temperatures in the single-bath method, but that no very severe injury was caused by any of the treatments. In studies on the germination of seeds treated by the modified hot-water method Tapke (*15*) has shown that the number of seeds which germinate in the soil is considerably smaller than the number which survive the blotter test. It is probable, therefore, that the lethal action of the most severe treatments especially was greater than was indicated by the blotter test and that the degree of injury would have been more apparent in a test in soil.

[4] Goens wheat is extensively grown under its synonym, Red Chaff, in sections of Indiana where loose smut is very prevalent. It is unusually susceptible to loose smut, and perhaps more than any other variety is subjected to modified hot-water treatment. For these reasons it has been included in many of the experiments reported here.

[5] Accession number of the Office of Cereal Investigations.

SMUT CONTROL

Untreated and treated wheat from six of the seed lots used in the germination test was employed in an experiment to determine the effects of the different single-bath treatments in controlling loose smut. On September 15, 1920, untreated seed and seed from each treatment of each of the six lots was sown in rod rows at the rate of 6 pecks per acre. The entire series of rod rows was sown in triplicate. In May, 1921, smutted heads were counted. The results are presented in Table 2. A zero in the table indicates that no smut was found in a complete examination of all heads in all three rows. The number of heads per row usually ran from 400 to 500. When less than 1 per cent of smut was present it is shown as T (trace), and the total number of smutted heads found in examining all three of the rows appears in parentheses. Other data represent the average percentages of loose smut determined by making a count of 200 heads in each of the three rows in a set.

TABLE 2.—*Percentages of loose smut in six lots of Goens wheat grown from seed untreated or treated with hot water, as specified, and sown in the field at Arlington Experiment Farm on September 15, 1920*

[T=trace (less than 1 per cent). The figures in parentheses show the number of smutted heads found in all three of the triplicated rows]

Treatment of the seed			Percentage of loose smut					
Kind and temperature	Duration		Lot 1	Lot 2	Lot 4	Lot 6	Lot 11	Lot 14
	Hours	Minutes						
Untreated			5	8	12	9	2	7
Modified method			0	0	0	0	0	0
Single-bath method:								
At 48° C	1	30	0	T (2)	2	1	0	T (4)
	2		0	0	0	0	0	0
	2	30	0	0	0	0	0	0
At 49° C	1		2	2	5	5	T (4)	3
	1	30	0	0	0	T (1)	0	T (1)
	2		0	0	0	0	0	0
		45	4	4	9	6	1	4
At 50° C	1		1	2	4	2	0	2
	1	15	0	0	T (1)	0	0	0
		30	5	8	12	8	1	6
At 51° C		45	3	4	7	2	T (1)	2
	1		0	1	T (2)	0	0	1

Table 2 shows that by the single-bath method complete smut control was obtained by soaking the seed at 48° C. for 2 hours and for 2 hours and 30 minutes, and at 49° C. for 2 hours. Only very slight traces of smut were found when the seed was soaked at 49° C. for 1 hour and 30 minutes, and at 50° C. for 1 hour and 15 minutes.

The summary of results obtained in 1920–21 indicates that the single-bath method can be used successfully to control loose smut with less injury to the seed than is caused by the modified hot-water treatment, as noted by Humphrey and Potter (*6*). At 48° C. the optimum duration of treatment for the control of smut without seed injury evidently lies between 1 hour and 30 minutes and 2 hours, and at 49° C. it is slightly above 1 hour and 30 minutes. At temperatures above 49° C. germination was considerably reduced, even when the seed was not soaked for a sufficient length of time to control the smut completely.

EFFECTS OF SINGLE-BATH HOT-WATER TREATMENTS IN 1921–22

GERMINATION

In the fall of 1921 single-bath treatments at 46° C. were included in the studies on smut control, and treatments at 47° C. were included in all of the studies. The treatments at 50° and 51° C. were not included in the yield tests because of their injurious effects on germination, even when applied for insufficient time to effect complete control of loose smut. In the germination tests in soil, four lots of Goens (Red Chaff) wheat from Indiana and one lot each of Fulcaster (C. I. 6162) and Purplestraw (C. I. 1915) wheats from Arlington Experiment Farm, Rosslyn, Va., were employed, except for the treatments at 46° C., in which only the four lots of Goens were used. All the seed was grown in 1921.

Treatments were applied on September 7 and 8, 1921, at the temperatures and during the time periods designated in Table 3. The grain then was spread to cool, left to dry at room temperatures for one week and packeted. On December 3, 1921, 100 untreated seeds and 100 seeds from each treatment of each of the six lots were sown in soil in greenhouse flats. One month later germination counts were made.

TABLE 3.—*Percentages of germination of six lots of wheat from seed untreated or treated with hot water, as specified, and sown in soil in the greenhouse, December 3, 1921*

Treatment of the seed			Percentage of germination						
Kind and temperature	Duration		Lot 16, Goens	Lot 17, Goens	Lot 19, Goens	Lot 21, Goens	Lot 26, Fulcaster	Lot 27, Purplestraw	Average
	Hours	Minutes							
Untreated			91	93	96	80	98	88	91.0
Modified method			74	53	76	54	66	58	63.5
Single-bath method:									
At 46° C.	2	30	94	91	95	66			86.5
	3		86	91	92	72			85.3
	3	30	88	91	93	68			85.0
	4		90	85	92	70			84.3
At 47° C.	2		86	81	94	74	88	80	83.8
	2	15	94	78	92	54	86	80	80.7
	2	30	85	86	86	66	82	94	83.2
	2	45	86	78	88	68	86	78	80.7
	3		89	76	86	44	78	80	75.5
At 48° C.	1	40	89	82	88	68	84	82	82.2
	1	50	87	86	86	58	88	78	80.5
	2		88	79	90	68	92	88	84.2
At 49° C.	1	35	89	79	86	70	86	88	83.0
At 50° C.	1	15	70	63	72	46	76	86	68.8
At 51° C.	1		66	63	66	62	70	72	66.5

Table 3 shows that the modified hot-water treatment reduced germination 27.5 per cent, or more than any other treatment. The single-bath treatments at 47° C. for three hours, at 50° C. for one hour and a quarter, and at 51° C. for one hour also caused injury, reducing germination 15.5, 22.2, and 24.5 per cent, respectively.

EMERGENCE OF SEEDLINGS

The reduced percentages of germination of treated seeds do not show all of the injurious effects of treatment, however. Frequently the emergence of the seedlings was retarded measurably. They

appeared weak and spindling, and the initial setback unquestionably was greater than indicated by the reduction in the number which survived. In order to show the effects of the various treatments on emergence, three lots of Goens wheat (Nos. 18, 20, and 22) grown in 1921 were treated on September 7 and 8, 1921, at the temperatures and during the time periods specified in Table 4. The seed then was spread to cool, left to dry at room temperature for one week, and packeted. On December 3, 1921, 50 untreated kernels of each of the three lots and 50 kernels from each treatment of each lot were sown in soil in greenhouse flats. Following the date of emergence of the first seedling, daily records of the number of seedlings which had emerged were taken for 15 days.

TABLE 4.—*Total number of seedlings of three lots of Goens wheat which had emerged at the end of the fifth to the nineteenth day after sowing, with final percentages of emergence, from 150 seeds untreated or treated with hot water, as specified, and sown in soil in the greenhouse December 3, 1921*

Treatment of the seed			Total seedlings emerged on the following number of days after sowing															Final emergence (per cent)
Kind and temperature	Duration		5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	
	Hours	Minutes																
Untreated			1	62	120	126	130	130	131	132	132	132	132	132	132	132	132	88.0
Modified method			0	2	12	25	46	55	62	69	71	74	78	79	80	80	80	53.3
Single-bath method:																		
At 46° C.	2	30	4	53	104	108	116	116	118	118	119	120	121	121	121	121	121	80.7
	3		3	48	95	109	115	115	116	119	120	121	122	123	123	123	123	82.0
	3	30	5	38	91	101	112	113	118	120	120	120	121	121	121	121	121	80.7
	4		3	29	85	98	104	107	113	115	117	118	118	119	119	119	119	79.3
At 47° C.	2		6	45	96	101	111	113	114	118	118	119	120	120	120	120	120	80.0
	2	15	1	27	94	104	107	107	111	114	117	117	117	117	118	118	118	78.7
	2	30	2	18	66	91	102	105	109	113	113	115	116	116	116	116	116	77.3
	2	45	1	24	70	86	91	95	98	100	100	103	105	105	105	105	105	70.0
	3		3	11	31	59	87	89	92	96	97	98	99	100	100	100	100	66.7
At 48° C.	1	40	4	38	82	99	107	110	114	115	115	116	117	117	117	117	117	78.0
	1	50	1	19	80	93	103	106	108	111	111	113	114	114	114	114	114	76.0
	2		0	10	77	92	102	104	107	109	110	111	112	112	112	112	112	74.7
At 49° C.	1	35	14	36	84	98	105	107	108	112	113	114	117	117	117	117	117	78.0
At 50° C.	1	15	1	6	35	56	63	69	70	72	72	74	75	75	75	75	75	50.0
At 51° C.	1		0	6	32	50	63	70	70	75	76	78	79	80	81	81	81	54.0

Table 4 shows that, in general, with increases in the severity of treatment as expressed by reduction in final percentage of emergence, the degree of retardation in the emergence of surviving seedlings also increased. Figure 1 shows this graphically for some of the treatments employed.

As shown later, the treatment at 48° C. for 1 hour and 50 minutes proved to be one of the most satisfactory for the single-bath method. The emergence and growth of seedlings from three varieties of machine-threshed wheat to which this treatment was applied, in comparison with that of seedlings from wheat treated by the modified method and from untreated wheat, are shown in Figure 2. The varieties, Currell (C. I. 3326), Purplestraw (C. I. 1915), and Goens, were grown on the Arlington Experiment Farm, Rosslyn, Va., in 1921. The seed was treated on July 11, 1921, spread out, and left to dry at room temperature until August 8. At this time 200 untreated seeds of each lot and 200 seeds from each of the treatments of each lot were sown in soil in flats in the greenhouse. Two weeks later some of the

flats were photographed (Fig. 2). One month after sowing germination counts were made. The average percentages of germination of the three lots were as follows: Untreated wheat, 88 per cent; wheat treated by the modified method, 66.8 per cent; wheat treated by the single-bath method, 81.7 per cent. These results indicate that the wheat treated by the modified method was injured rather severely; but, as shown in Figure 2, the injurious effects undoubtedly were greater than indicated by the reduction in germination. The emergence and growth of the seedlings were retarded in varying degrees; hence, uneven stands were obtained. The emergence of

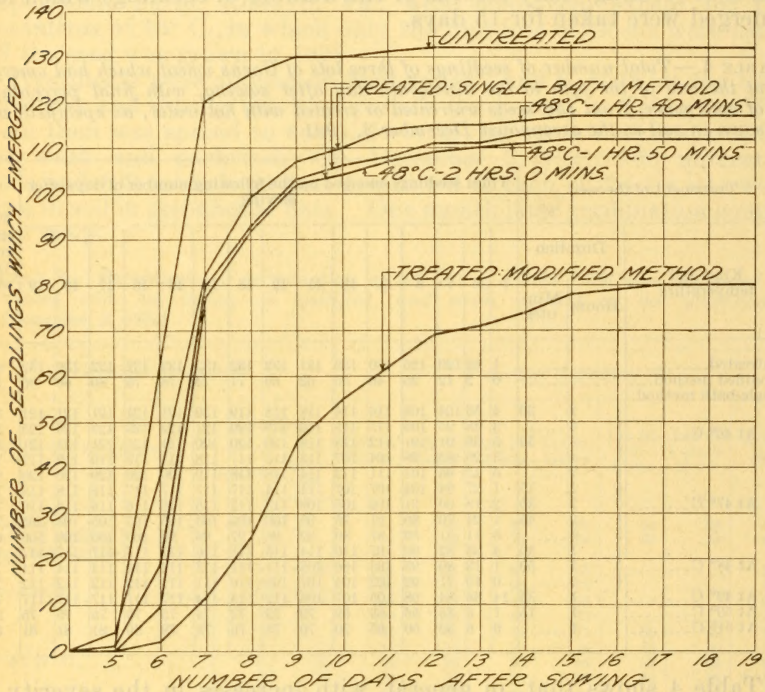

FIG. 1.—Diagram showing the comparative rates of emergence and number of wheat plants which emerged from seed untreated, treated by the modified hot-water method, or treated by the single-bath method at 48° C. for 1 hour and 40 minutes, 1 hour and 50 minutes, and 2 hours, respectively

seedlings from wheat treated at 48° C. for 1 hour and 50 minutes was fairly even, although somewhat retarded at the start. Fourteen days after sowing, however, as shown in Figure 2, the seedlings appeared almost as vigorous as those from untreated seed.

YIELD AND CONTROL OF LOOSE SMUT AND BUNT

In an experiment to determine the effects of single-bath hot-water treatments on the control of loose smut and bunt three lots of Goens wheat (Nos. 18, 20, and 21) were used. They were grown in Indiana in 1921 and contained relatively high percentages of loose smut. Some of each lot was dusted thoroughly with bunt spores, and quantities were treated during the period from October 11 to 15, 1921.

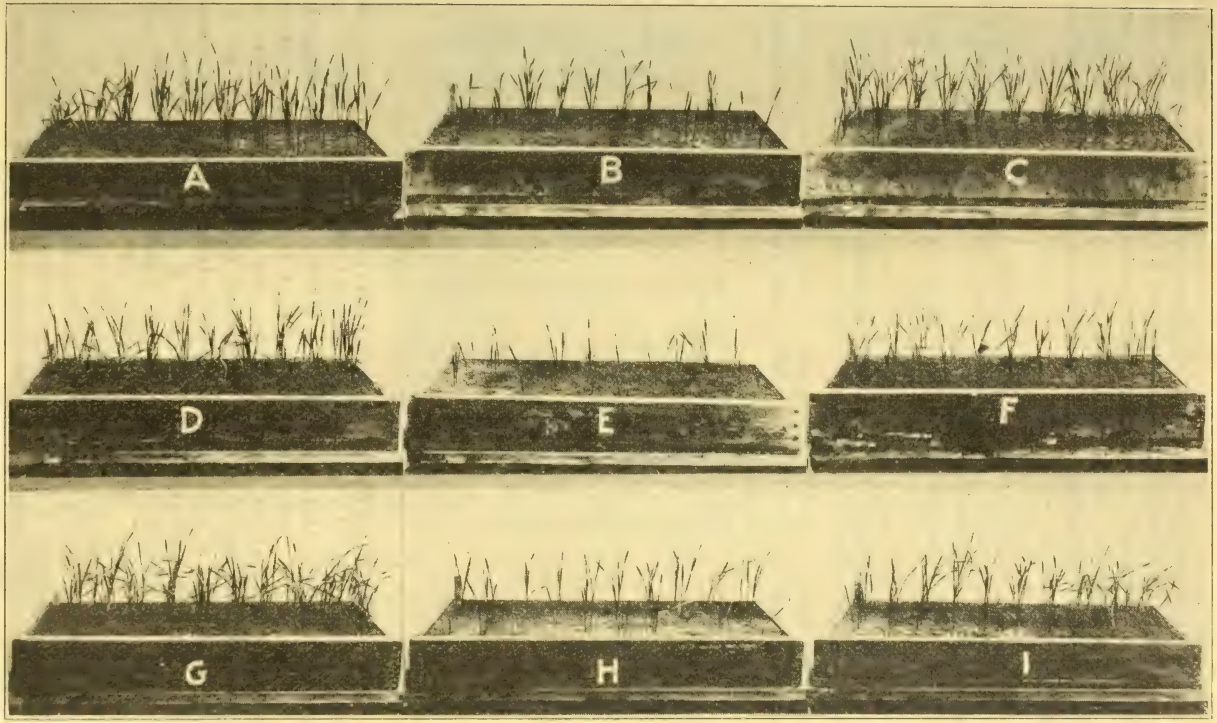

FIG. 2.—Comparison of some of the effects of the modified and the single-bath hot-water treatments on the germination and emergence of seedlings from treated machine-threshed wheat

A, B, C, Currell wheat; D, E, F, Purplestraw wheat; G, H, I, Goens wheat; A, D, G, seed not treated; B, E, H, seed treated with hot water by the modified method; C, F, I, seed treated with hot water by the single-bath method at 48° C. for 1 hour and 50 minutes

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The grain was left to dry at room temperature until October 20, when both untreated and treated seeds were sown in a triplicate series in rod rows at the rate of 6 pecks per acre. The results are presented in Table 5. A zero in the table indicates that no smut was found in a complete examination of the plants in all three rows. When less than 1 per cent of smut was present it is shown as T (trace), and the total number of smutted heads found in an examination of all three rows is given in parentheses. The other data represent the average percentages of smut determined by making a count of 200 heads in each of the three rows in a set.

TABLE 5.—*Percentages of loose smut and bunt in three lots of Goens wheat grown from seed untreated or treated with hot water as specified, and sown in the field at Arlington Experiment Farm October 20, 1921*

[T=trace (less than 1 per cent). The figures in parentheses show the number of smutted heads found in all three of the triplicated rows]

Treatment of the seed			Percentage of loose smut			Percentage of bunt		
Kind and temperature	Duration		Lot 18	Lot 20	Lot 21	Lot 18	Lot 20	Lot 21
	Hours	Minutes						
Untreated			3.8	12.3	6.0	43.0	47.6	45.8
Modified method			0	0	0	T (5)	T (5)	T (7)
Single-bath method:								
At 46° C.	2	30	T (1)	0	0	4.5	1.5	6.0
	3		0	0	0	2.0	4.0	2.0
	3	30	0	0	0	1.0	2.0	4.5
	4		0	0	0	2.0	1.0	4.5
At 47° C.	2		0	0	0	0	1.0	T (3)
	2	15	0	0	0	T (9)	1.0	T (3)
	2	30	0	0	0	T (6)	0	1.0
	2	45	0	0	0	0	T (6)	0
	3		0	0	0	0	T (3)	T (3)
At 48° C.	1	40	0	0	0	0	T (6)	T (10)
	1	50	0	0	0	T (10)	T (10)	T (6)
	2		0	0	0	T (9)	T (6)	T (9)
At 49° C.	1	35	0	0	0	T (2)	T (1)	T (6)
At 50° C.	1	15	0	T (1)	0	0	0	0
At 51° C.	1		T (1)	T (1)	0	0	0	0

Table 5 shows that all of the treatments completely controlled loose smut except those at 46° C. for 2 hours and 30 minutes, at 50° C. for 1 hour and 15 minutes, and at 51° C. for 1 hour. These treatments reduced the amount of loose smut to a slight trace. In spite of an unusually heavy infestation, bunt infection was reduced to a trace or completely controlled by all of the treatments except those at 46° C. and by the treatments at 47° C. for time periods less than 2 hours and 45 minutes. The treatments at 50° and 51° C. effectively controlled both loose smut and bunt, but reference to Table 4 shows that they severely injured the seed. The treatments at 49° C. for 1 hour and 35 minutes, and at 48° C. for 1 hour and 40 minutes, for 1 hour and 50 minutes, and for 2 hours completely controlled loose smut and reduced bunt infection to a trace, and the treated seed germinated as well (Table 4) as that from the longer treatments at 47° C., which approximated their efficacy in smut control.

Table 5 shows that treatments at lower temperatures and of longer duration are more effective in controlling loose smut than in controlling bunt and that treatments at higher temperatures and of shorter duration are more effective in controlling bunt than they are in controlling loose smut.

An experiment also was conducted in 1921–22 to determine the effects of the single-bath hot-water treatments on yield and further to determine their effects on the control of loose smut. Three lots of Goens wheat (Nos. 16, 17, and 19) and one lot each of Fulcaster (C. I. 6162) and Purplestraw (C. I. 1915) wheats were used. The Goens lots were grown in Indiana in 1921 and contained relatively high percentages of loose smut. The other lots were grown on Arlington Experiment Farm in 1921 but contained no loose smut.

A definite quantity of each lot was weighed and measured, treated on October 13, 1921, spread in thin layers, and dried for one week at room temperature. The treated seed had regained its original weight and volume at the end of this period.

On October 21 the untreated and treated seed was sown in rod rows on Arlington Experiment Farm at the rate of 6 pecks per acre. Five plats were used, and each plat was divided into an east and west section. Each of these 10 sections contained 55 rows, which comprised 11 successive rows of each of the lots 16, 17, 19, 26, and 27 in their order. The first 9 of the 11 rows were sown with seed treated by the single-bath method in the manner and order shown in Table 6, while the tenth and eleventh rows were sown with seed treated by the modified method and with untreated seed, respectively. The untreated control and each of the treatments were therefore represented by 10 rod rows of each of 5 different lots of seed, or a total of 50 rod rows. The results are presented in Table 6. A zero in the columns containing the average percentages of loose smut shows that no smut was found in a complete examination of each of the 10 rows sown from the seed treated as specified. When less than 1 per cent of smut was present it is shown by T (trace), and the total number of smutted heads found in an examination of all 10 rows appears in parentheses. Other data represent the average percentages of smut determined by making a count of 100 heads in each of the 10 rows.

TABLE 6.—*Loose-smut infection and yields of wheat from five lots of seed untreated or treated with hot water, as specified, and sown on an east and on a west section of each of five plats in the field at Arlington Experiment Farm October 21, 1921*

[T=trace (less than 1 per cent). The figures in parentheses show the number of smutted heads found in all 10 of the rod rows]

Treatment of the seed			Average acre yields (bushels)														Average per centage of loose smut[1]		
	Duration		On east sections of plats						On west sections of plats						Sections combined	Increase of west over east sections			
Kind and temperature	Hours	Minutes	Lot 16	Lot 17	Lot 19	Lot 26	Lot 27	Average	Lot 16	Lot 17	Lot 19	Lot 26	Lot 27	Average			Lot 16	Lot 17	Lot 19
Untreated			35.5	34.5	31.7	26.2	37.3	33.0	36.5	38.0	30.7	31.6	34.7	34.3	33.7	1.3	7.2	9.0	13.0
Modified method			27.2	21.1	23.8	21.5	25.8	23.9	30.5	26.2	27.8	30.3	31.2	29.2	26.6	5.3	0	0	0
Single-bath method:																			
At 47° C	2		25.8	28.9	27.9	28.8	33.8	29.0	32.3	32.3	34.1	31.4	32.1	32.4	30.7	3.4	0	T (6)	T (5)
	2	15	29.8	31.7	31.6	27.0	28.7	29.8	34.2	34.7	36.7	29.7	33.2	33.7	31.8	3.9	0	T (1)	0
	2	30	30.8	33.8	31.6	25.9	28.6	30.1	33.1	32.9	34.2	31.1	31.2	32.5	31.3	2.4	0	0	0
	2	45	30.9	30.0	30.2	24.9	28.3	28.9	31.3	34.5	34.8	32.7	31.5	33.0	31.0	4.1	0	0	0
	3		29.5	30.9	30.1	26.8	26.2	28.7	32.1	34.5	31.7	29.5	33.9	32.3	30.5	3.6	0	0	0
At 48° C	1	40	33.4	33.3	33.0	27.1	28.5	31.1	37.0	38.2	33.9	32.2	35.4	35.3	33.2	4.2	0	T (3)	0
	1	50	31.7	33.2	31.7	27.7	27.7	30.4	35.4	36.1	34.2	28.0	35.4	33.8	32.1	3.4	0	0	0
At 49° C	2		33.6	31.1	29.6	28.1	27.4	30.0	34.3	36.1	34.4	30.0	31.3	33.2	31.6	3.2	0	0	0
	1	35	33.3	31.5	32.9	28.9	29.6	31.2	35.8	39.5	36.5	33.6	33.5	35.8	33.5	4.6	0	0	0

[1] Lots 26 and 27 contained no loose smut.

Some of the facts brought out in Table 6 are: (1) That all of the treatments completely controlled loose smut except those at 47°C. for 2 hours and 2 hours and 15 minutes, and at 48° for 1 hour and 40 minutes, these treatments reducing the amount of loose smut to a trace; (2) that the plants from untreated seed outyielded those from any of the treated seed, although three of the lots (Nos. 16, 17, and 19) contained a relatively high percentage of loose smut; (3) that plants from seed given any of the single-bath treatments outyielded plants from seed treated by the modified method; (4) that some of the single-bath treatments, especially those at 48° C. for 1 hour and 40 minutes and at 49° for 1 hour and 35 minutes, reduced the yield only very slightly; (5) that increases in the duration of treatment as short as 10 minutes at 48° C. were accompanied by decreases in yield; and (6) that without exception the average yields for the five lots of plants from untreated seed and from seed given any of the treatments were higher on the west sections than on the east sections of the plats, indicating less favorable soil conditions on the east sections. It is noteworthy that this reduction amounted to only 1.3 bushels per acre in plants grown from untreated seed and to approximately two to four times this amount in plants grown from treated seed. The greatest reduction occurred in plants from seed treated by the modified hot-water method. In the absence of data on the germination of untreated and treated seed, it is impossible to state whether this reduction was due to a decreased emergence of seedlings from the treated wheat or to a lessened post-germination capacity on the part of the plants which developed from treated wheat or both. It is evident, however, that the soil conditions under which the treated seed is sown may play an important part in the complex of factors which eventually determine the effects of treatment on yield.

TABLE 7.—*Test weight per bushel of wheat of five different lots grown from seed untreated or treated with hot water, as specified, and sown in the field at Arlington Experiment Farm October 21, 1921*

Treatment of the seed			Bushel weight (pounds)					
Kind and temperature	Duration		Lot 16, Goens	Lot 17, Goens	Lot 19, Goens	Lot 26, Fulcaster	Lot 27, Purple-straw	Average
	Hours	Minutes						
Untreated			55.00	53.85	55.30	51.25	55.60	54.20
Modified method			55.20	54.50	54.80	51.55	55.50	54.31
Single-bath method:								
At 47° C.	2		54.36	54.45	54.70	51.35	55.50	54.07
	2	15	54.75	54.40	54.35	50.62	55.30	53.88
	2	30	54.30	54.00	54.81	51.00	55.30	53.88
	2	45	54.56	53.25	54.55	50.85	55.50	53.74
	3		54.40	54.45	53.19	50.94	55.30	53.66
At 48° C.	1	40	55.00	54.45	54.45	51.19	54.00	53.82
	1	50	55.30	54.10	54.75	50.85	55.60	54.12
	2		55.10	54.10	54.70	50.90	55.25	54.01
At 49° C.	1	35	55.30	54.00	55.40	50.80	54.50	54.00

Pipal (*13*) states that apparently beneficial effects other than smut control are obtained through treatment of the seed by the modified hot-water method. For example, plants from treated seed in many cases produced heavier, plumper grain than plants from untreated seed. In order to determine the effect of the different treatments

on the weight of grain, the test weight per bushel was taken on all of the wheat grown from the seed of the five lots. In the description of the plan of this experiment it was noted that each of the five plats was divided into two sections, which were duplicates. In making the study of weight of grain, wheat from the duplicate rows in the two sections was thoroughly mixed. This was necessary in order to have a sufficient quantity to fill the cup of the tester. This procedure was carried out for the grain grown from untreated and treated seed of each lot in each of the five plats. The results are presented in Table 7.

Table 7 shows that the weight of grain from treated seed was slightly greater than that from untreated seed where the modified hot-water method was employed and slightly less where the single-bath method was used. In all instances the differences were very slight. Because of varying amounts of injury from treatment, especially in the case of the modified hot-water method, the quantity of viable seed frequently is reduced, and a thin stand results. Under this condition the plants from treated seed might produce grain of higher weight per bushel than the plants from untreated seed, but without relation, however, to any direct effects of treatment.

With regard to the relative effectiveness of the various single-bath treatments, a study of the foregoing data shows that the treatments at 48° C. for 1 hour and 50 minutes and at 49° for 1 hour and 35 minutes gave the most satisfactory results. They controlled loose smut completely and bunt effectively, and the reductions in germination and yield were relatively small. The treatment at 48° for 1 hour and 40 minutes slightly surpassed the treatment at 48° for 1 hour and 50 minutes in most respects, but it was less effective in controlling loose smut. None of the treatments at 47° appeared to have particular advantage. Those of shorter duration failed to control either loose smut completely or bunt effectively, or both. Moreover, all of the treatments at 47°, especially those of longer duration, reduced the yield more than the treatments noted above. In view of these facts the following experiments with the single-bath method were confined to the treatments at 48° for 1 hour and 50 minutes and at 49° for 1 hour and 35 minutes.

EFFECTS OF SINGLE-BATH HOT-WATER TREATMENTS IN 1923–24

GERMINATION IN RELATION TO INTEGRITY OF SEED COAT

In a previous article (*15*) the writer showed that the condition of the seed coat is a most important factor in determining the reduction in germination resulting from the modified hot-water treatment. When the seed coats of wheat were unbroken the modified treatment reduced the germination very little, if at all; but when the seed coats were broken, the reduction in germination always was high, especially when the break was over the embryo. In order to determine the effects of the single-bath method on germination in relation to integrity of seed coat, an experiment was conducted with hand-threshed seed. Five varieties, Currell (C. I. 3326), Forward (C. I. 6691), Fultz (C. I. 1923), Purplestraw (C. I. 1915), and Stoner (C. I. 2980), were used. Each variety was divided into five lots of 60 seeds each. The seed coats were left unbroken in the first lot. In lots 2 to 5 a small part of the coat was very carefully broken on February 7, 1924, with a sharply pointed needle in the following locations: Lot 2, directly

over the embryo; lot 3, over the endosperm, about one-eighth of an inch above the embryo; lot 4, over the endosperm, at the brush end; and lot 5, over the endosperm, on each cheek in a location behind the embryo.

The five lots of each variety were then divided into three equal parts. One part was left untreated, one part was treated by the modified method, and one part was treated by the single-bath method. In the latter method the treatment at 48° C. for 1 hour and 50 minutes was selected. Immediately after treatment on February 8, 1924, the seed was spread and left to dry for six days at room temperature. The untreated and treated grain was then sown in soil in greenhouse flats, and the seedlings were counted 30 days later. All of the varieties reacted similarly. Averaged results from all varieties are presented in Table 8.

TABLE 8.—*Percentages of germination of hand-threshed seed wheat untreated or treated with hot water, as specified, when the seed coats were unbroken or broken over the embryo or over the part of the endosperm described, as shown by greenhouse tests in 1924*

[The percentages shown are the average results from the five varieties, Currell, Forward, Fultz, Purple-straw, and Stoner]

Treatment of the seed	Percentage of germination when seed coats were—				
	Unbroken	Broken over embryo	Broken over endosperm		
			⅛ inch above embryo	Over brush end	On each cheek behind embryo
Untreated	96	94	92	93	88
Treated by the modified hot-water method	94	0	78	67	49
Treated by the single-bath method at 48° C. for 1 hour and 50 minutes	94	26	88	84	78

Table 8 shows (1) that the amount of injury from treatment by the single-bath and by the modified method is determined by the condition of the seed coat, and (2) that when the seed coats are broken as noted the single-bath treatment is less injurious to germination than the modified treatment. The practical significance of this fact becomes apparent in view of the finding by Nobbe (*12*), Kühn (*9*), Schellenberg (*14*), Von Tubeuf (*16*), Volkart (*17*), Burmester (*3*), Walldén (*18*), Hurd (*7*), Tapke (*15*), and others that machine threshing damages seed coats. In view of the data presented in Table 8 it seems safe to assume, therefore, that seed treated by the single-bath method will suffer less injury to germination than seed treated by the modified hot-water method. Nobbe (*12*), Volkart (*17*), Walldén (*18*), and others also have pointed out that the amount of cracking of seed coats by the threshing machine varies from year to year, and that it is more prevalent in dry years. Schellenberg (*14*) has shown that machine threshing usually damages the larger kernels. It is therefore evident that the lesser amount of germination injury caused by the single-bath method may vary from year to year and with the variety used. When the seed coats were unbroken, as shown in Table 8, the percentage of germination of seed treated by the modified hot-water method was as high as that of seed treated

by the single-bath method. On the other hand, when the seed coats were broken the percentage of germination of seeds treated by the modified hot-water method ran from 10 to 29 per cent lower than that of seeds treated by the single-bath method, depending upon the location of the break in the seed coat.

It has been noted that germination was markedly reduced as a result of hot-water treatment when the seed coats were broken and that very little or no reduction in germination was brought about when the seed coats were intact. It was noted also that the seed coats are more susceptible to breakage in threshing in dry years and less susceptible in wet years. It is evident, therefore, that the effects of hot-water treatments on germination are ultimately dependent to a considerable extent on the weather conditions which prevail during the ripening, harvesting, and threshing of the grain, and that we may expect variable responses to treatment from year to year. On this point the observations of Baudyš (*2*) are interesting. He notes that a variety may differ in susceptibility to hot-water injury from year to year and therefore requires annual determinations of the proper temperatures for the treatment bath.

YIELD

In studies previously reported by the writer (*15*) some evidence was obtained indicating that the injurious effects of the modified hot-water treatment may extend into the later stages of plant growth. The results presented in Table 6 plainly show that the plants from treated seed suffered a lessened capacity to withstand unfavorable soil conditions. In the absence of data on the germination of untreated and treated seed, however, it is impossible to state whether this difference was due to a decreased emergence of seedlings from the treated wheat or to a lessened post-germination capacity on the part of the plants which developed from treated wheat.

In a yield test conducted in 1923–24 an attempt was made to study further the post-germination effects of hot-water treatments. To this end unsmutted seed was used, and in some of the plats the rate of seeding of the treated wheat was increased to compensate for the reduction in germination resulting from treatment. Any differences which might have affected the yields of the plants from untreated and treated seed were therefore eliminated, except the differences brought about by treatment. On September 22 definite quantities of each of two lots of wheat grown on Arlington Experiment Farm in 1923 were weighed and measured, treated as shown in Table 9, spread in thin layers, and left to dry. On October 2, 200 untreated seeds and 200 seeds from each of the treatments of each lot were sown at Arlington Experiment Farm on the land which later was used for the yield test. At this time the treated seed had regained its original weight and volume. Germination counts were taken after three weeks. On October 27 the untreated and treated seed of both lots were sown in fortieth-acre plats. In half of the plats sown with treated seed the rate of sowing was increased to compensate for reduction in germination. The drill which was used could not be adjusted to differences in rates less than one-half peck. Therefore the nearer half-peck rate was used when the calculated rate fell between half pecks. Tests made previous to sowing showed that the drill delivered the seed at rates which closely approximated the rates at which it was set.

TABLE 9.—*Individual and average percentages of emergence and yields of two lots of smut-free wheat from seed untreated or treated with hot water, as specified, and grown at Arlington Experiment Farm in 1923–24*

[The treated seed was sown at the same rate as the untreated seed, 6 pecks per acre, or plus an allowance to compensate for the reduction in germination. The loss or gain shown in the last column is calculated from the interpolated yield of the untreated control, which is given in parentheses]

Variety and plat	Treatment of the seed				Percentage of germination	Rate of sowing (pecks)	Acre yields (bushels)	
	Method	Temperature (° C.)	Duration				Actual	Loss (−) or gain (+) from treated seed
			Hr.	Min.				
Mammoth Red (C. I. 2008):								
No. 1	Border plat					6.0		
No. 2	Untreated				84	6.0	47.3	
No. 3	Modified				68	6.0	42.4	−2.9 (45.3)
No. 4	do				68	[1] 7.5	41.8	−1.5 (43.3)
No. 5	Single bath	49	1	35	79	6.0	41.0	−0.3 (41.3)
No. 6	Untreated				84	6.0	39.3	
No. 7	Single bath	49	1	35	79	[1] 6.5	37.7	−.3 (38.0)
No. 8	do	48	1	50	73	6.0	37.9	+1.1 (36.8)
No. 9	do	48	1	50	73	[1] 7.0	38.4	+2.8 (35.6)
No. 10	Untreated				84	6.0	34.4	
Poole (C. I. 3489):								
No. 11	do				92	6.0	35.0	
No. 12	Modified				81	6.0	32.4	−4.6 (37.0)
No. 13	do				81	[1] 7.0	35.6	−3.4 (39.0)
No. 14	Single bath	49	1	35	77	6.0	38.5	−2.5 (41.0)
No. 15	Untreated				92	6.0	43.0	
No. 16	Single bath	49	1	35	77	[1] 7.0	40.6	−3.9 (44.5)
No. 17	do	48	1	50	88	6.0	42.2	−3.8 (46.0)
No. 18	do	48	1	50	88	[1] 6.5	44.0	−3.5 (47.5)
No. 19	Untreated				92	6.0	49.0	
No. 20	Border plat					6.0		

[1] The drill used could not be adjusted to differences in rates less than one-half peck. The compensated rates as calculated were therefore adjusted to the nearest half-peck rate. All of them are slightly higher than the calculated rate.

Table 9 shows that plants from untreated seed outyielded those from treated seed in 10 cases out of 12. The average yield of all of the plants from seed treated at 48° C., 49°, and by the modified method, respectively, was 0.7, 1.9, and 3.3 bushels per acre less than the average yield of all of the plants from seed not treated (41.3 bushels per acre).

When treated wheat was sown at an increased rate, so that the quantity of viable seed sown was the same as that of untreated wheat, the average yield still was less by 1.65 bushels per acre than that of all plants from seed not treated. These data suggest that the injurious effects of hot-water treatments may extend beyond the germination period and into the later stages of plant growth.

For the years 1922 and 1924 (yield tests were not conducted in 1923) the average acre yields of plants from untreated and treated seed were as follows:

	Bushels
Seed not treated	37.5
Seed treated by the modified method	32.3
Seed treated at 48° C. for 1 hour and 50 minutes	36.4
Seed treated at 49° C. for 1 hour and 35 minutes	36.5

METHODS OF APPLYING SINGLE-BATH TREATMENTS

The data presented in the foregoing pages show that better results were consistently obtained from some of the single-bath treatments

than from the modified treatment. It appears, however, that the former would be considerably more difficult to apply than the modified treatment. In this regard it was suggested that the single-bath method might be applied with considerable facility to small batches by placing half-filled sacks of wheat on racks which could be lowered into and raised out of a large tank containing water which was mechanically agitated and maintained at a constant temperature. In order to determine whether agitation of the water could be substituted for that of the sacks, an experimental tank was constructed, as shown in Figure 3. There were two racks, one being shown suspended in the plate, each having a capacity of six sacks of wheat. The racks could be raised or lowered by means of chain blocks. In the latter position they came to rest side by side, with the bottom tray of each rack directly over a spiral agitator. The agitators were 9 inches in diameter and extended throughout the length of the tank. In the studies of heat penetration the spirals were revolved at a speed which caused a very vigorous agitation and a uniform distribution of temperature throughout the water. The temperature was maintained by a thermostatic device which injected steam into the water when necessary. Burlap sacks and the more tightly woven seamless cotton or mill sacks of 2-bushel capacity were employed in the experiments. They were half filled with wheat, tied at the top to provide ample room for the swelling of the grain, and laid on one side. Two sacks were placed on each of the trays. The bulb of a long-stemmed thermometer was carefully forced through the side of the sack under observation and inserted in the center of the mass of grain. The rack was then lowered into the water, which was agitated and maintained at 48° C. Tests were made with sacks placed on a bottom tray directly over the agitator, on a top tray, and with one or both agitators active. The temperatures registered were recorded at intervals of five minutes, and the tests were discontinued after the temperature in the mass of grain reached 48° C. The results are presented in Table 10.

TABLE 10.—*Time necessary to raise the temperatures of lots of wheat in burlap and in cotton sacks to 48° C. when immersed in water maintained at 48° C.*

[The sacks were placed on racks at different distances from one or two active agitators]

Test sack			Number of agitators active	Temperature (° C.) in center of sacked wheat mass after the number of minutes specified									
Kind	Location	Distance from agitator		5	6	10	15	20	22	25	30	35	38
		Inches											
Cotton	Bottom tray	4.5	2	36.9	------	41.7	45.8	47.7	48.0	------	------	------	------
Burlap	----do ------	4.5	2	47.5	48.0	------	------	------	------	------	------	------	------
Do	Top tray ------	22.5	1	34.0	------	42.8	43.8	45.0	------	46.0	46.8	47.6	48.0

Table 10 shows (1) that the time required for penetration of heat through a burlap sack was approximately one-fourth that required for a cotton sack, (2) that in burlap sacks rapid penetration occurred only when the sack was very close to the agitators, and (3) that reduction of agitation and increase of distance from the source of agitation

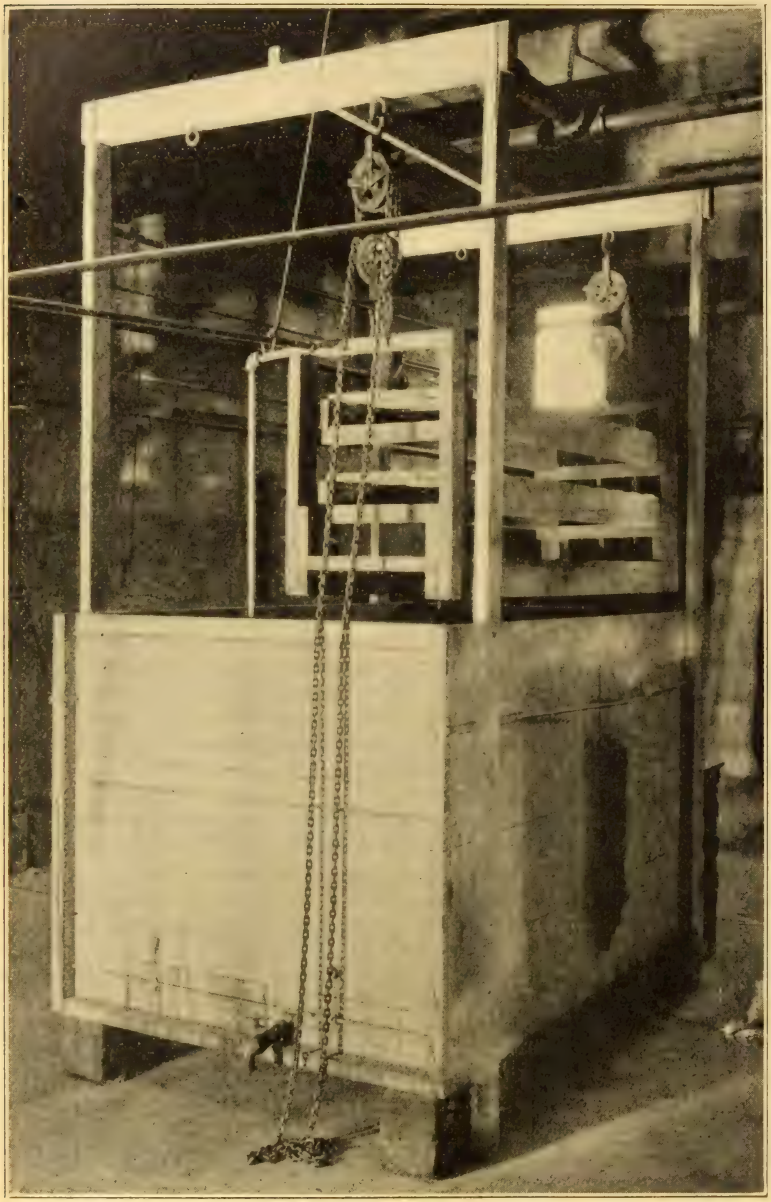

FIG. 3.—Apparatus used in studies to determine the rate of heat penetration in wheat in burlap and cotton sacks immersed in hot water

greatly decreased the rate of penetration. Agitation of the water alone therefore appears hardly practicable. It would seem, however, that agitation of the sacks would be necessary only for a short time at the beginning of the treatment, and that it could be discontinued as soon as the temperature throughout the mass of sacked wheat reached the temperature of the treatment bath. In the application of the 10-minute bath of the modified hot-water treatment, for example, agitation of the sacks in the water at 54° C. undoubtedly effects rapid penetration of the heat; otherwise the successful control of loose smut would not be so uniformly obtained.

Single-bath treatments could not be employed at central or community plants as usually equipped without a material reduction in the daily output of the plants. The successful adoption of treatments of this nature, therefore, seems dependent upon the development of practical methods and machinery which will facilitate their application.

The market offers two kinds of machines which could be used in combination to treat large quantities of wheat by the single-bath method and to dry the seed so treated. The first kind frequently is used in canneries and is equipped to carry seeds of various kinds through hot water by means of endless belts or screw conveyers. The rate of intake and discharge of the seeds, the temperature of the water, and the speed of the conveyers may be definitely fixed by mechanical regulators. Grain thus treated could then be passed through a machine of the second type referred to, a rotary grain drier. Here drying is effected by currents of hot air as the grain slowly passes through a revolving cylinder. The rate of drying, within limits, may be automatically controlled by regulation of the air temperature and the speed of the revolving cylinder. Under our present system of seed treatment, however, the use of machines of this kind would involve a very high overhead expense. This would follow because the machines would be used only for a short period prior to sowing and because their efficiency would be reduced by the necessity of treating many small seed lots and of keeping each lot separate.

STEAM TREATMENTS

One of the chief objections to hot-water treatment is the fact that the grain becomes wet and swollen. If the treated wheat is spread to dry before sowing, the procedure involves time, labor, space, and some risk of loss through sprouting or freezing. If it is planned to sow shortly after treatment, some difficulties also may be encountered: (1) The weather may not permit; (2) it is difficult to adjust accurately the rate of seeding of the swollen grain, and thin stands frequently result; (3) the water in the seed causes it to germinate independently of the soil moisture, and if dry weather follows seeding the stand may be injured severely; and (4) the practice tends to congest the work of treatment when it is done at a community seed-treatment plant. Any net gain which otherwise might result from treatment thus may be reduced or resolved into an actual loss.

A means for satisfactorily drying treated wheat would do much to popularize control through elimination of the difficulties enumerated. However, a practical machine for drying treated wheat for use, particularly at seed-treatment plants, has not been developed. It would be necessary to dry separately each lot of grain treated, in order to

avoid mixing different lots and varieties. This would require a drier of special construction, entail a large amount of work, and probably add so much to the cost of treatment as to make it unprofitable. It has been suggested, however, that the commercial grain drier might be employed advantageously both to treat and to dry wheat in quantities large enough to supply clean seed for an entire community. A system of this kind would greatly facilitate the establishment of smut-free areas. It has been the experience in the State of Indiana, according to Gregory (*5*), that the establishment of such areas "will greatly reduce the dangers of the spread of the smut," and it appears that wheat thus can be maintained free from loose smut for several years.

PREVIOUS INVESTIGATIONS

The use of grain driers and other kinds of drying apparatus in controlling loose smut of wheat and barley, or both, has been reported by a number of workers. A comprehensive review is given by Appel and Riehm (*1*). Later Lind (*10*) conducted experiments along this line. In general, the seed was previously soaked for varying periods or soaked and left to stand wet for periods of different length. The grain then was subjected to currents of dry hot air at temperatures high enough to control the parasite and to dry or partially dry the seed. Satisfactory results followed in some cases, particularly when special laboratory apparatus was used. Serious difficulties arise in attempting to standardize such treatments, however, because the hot dry air passing around soaked grain causes rapid evaporation and with it wide variation in temperature. Obviously the successful application of a thermal treatment involving large quantities of seed grain precludes a positive control of temperature. A saturated recirculating atmosphere was therefore employed in the following experiments to eliminate evaporation and its attending difficulties. By this means it was possible to maintain temperatures with a plus or minus variation not in excess of 0.2° C.

METHODS AND MATERIALS

There are two types of grain driers in general use, upright and rotary. In both types there are many different designs. In the rotary type drying is effected by currents of hot air as the grain slowly passes through a revolving cylinder, and in the upright type as the grain slowly flows through channels from the top to the bottom of the drier. An upright drier was used in the experiments recorded here. (Fig. 4.) This machine, though smaller, was like the standard sizes. It had a capacity of 2 bushels of wheat and was provided with a return pipe, so that the air could be recirculated. This return pipe runs along the side opposite that shown in Figure 4. The air was forced through the channels containing the grain by a powerful motor-driven fan. A recording thermometer was used to regulate the temperature in the drier. Steam before entering the machine passed through a thermostatically controlled valve which was opened or closed by air pressure. The latter in turn was controlled by a sensitive bulb. The bulb was inserted in the machine about 30 inches in front of the steam outlet. It was found that the amount of steam necessary to raise the temperature to the desired degrees (46° to 49° C.) was more than ample to keep the recirculating air saturated.

In beginning the treating operation, a quantity of wheat (about 80 pounds) nearly sufficient to fill the drier when swollen was soaked in cold water for four hours. Simultaneously, wheat from the lot or lots under experimentation was soaked in long, narrow, cheesecloth bags approximately 2 inches wide and 10 inches long. The bags were half filled, to allow room for swelling. The drier then was almost filled with the wheat soaked in bulk, and the cheese-

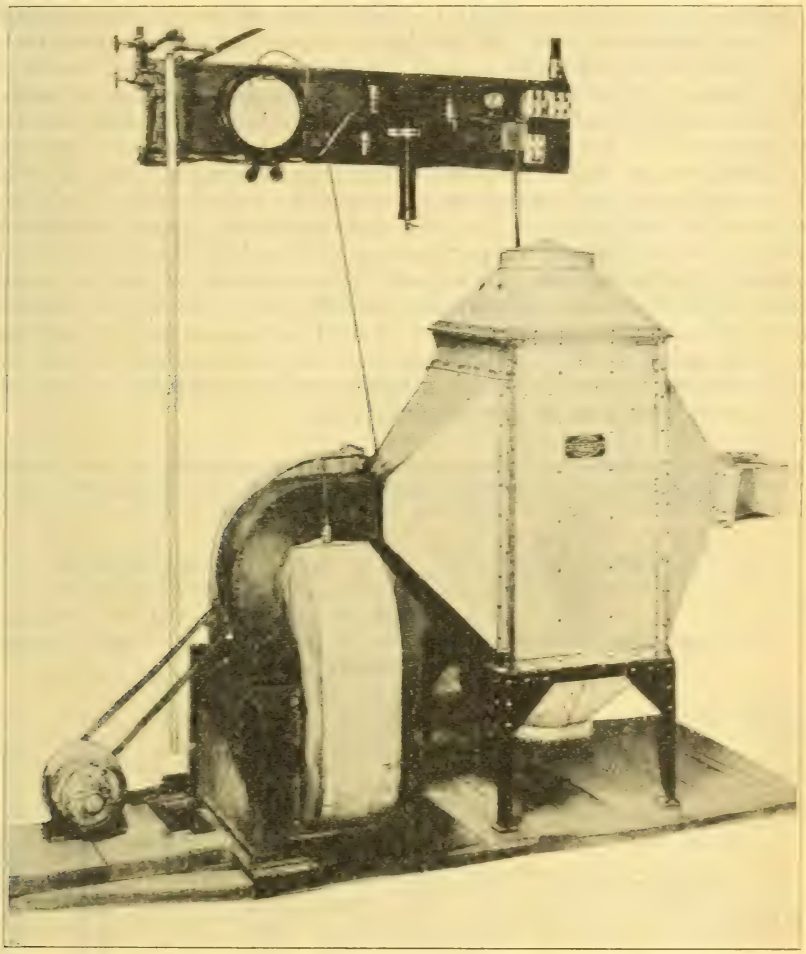

FIG. 4.—Grain drier and thermo-regulating apparatus used in experiments with steam treatments

cloth bags containing the grain under experimentation were buried in the mass so that their tops were several inches beneath the surface. In all cases treatment in the drier was begun by admitting steam through an auxiliary valve, so that the temperature of the grain was raised gradually to the desired degree during a period of 15 minutes, after which the temperature was maintained by automatic thermo-regulation, as already described. The temperatures were maintained with a plus or minus variation not in excess of 0.2° C. The duration

of treatment was reckoned from the moment that steam was first applied. At definite intervals one or more bags were pulled out of the mass of grain and out of the drier by means of a string attached to the top of each bag and running to the outside of the drier through a small hole in the lid. The bags were removed from the drier while the lid was momentarily raised. The wheat was released from the bags immediately after treatment and spread in a thin layer to cool. Treated seed was left to dry five days or more at room temperatures, to reduce its moisture content to about that of the untreated seed. The post-treatment methods employed in making germination tests in soil, etc., were the same as used for seed treated with hot water.

On account of the necessity for removing samples of wheat from the drier at successive intervals, as noted above, it was not possible to dry the grain in the machine. In practice this would involve cutting off the inflow of steam into the drier, substituting hot air as ordinarily employed, and switching a damper to provide for circulation instead of recirculation of the air. No experiments were conducted to determine the highest temperatures which could be used with safety in drying treated wheat. In regard to the artificial drying of wheat treated with hot water, Humphrey and Potter (*6*) state "It will be safer not to use temperatures above 150° F. after the grain is surface dry. The grain itself should not reach a temperature above 140° F., and if the circulation of air is inadequate temperatures as low as 110° F. will be injurious if long continued."

TABLE 11.—*Individual and average percentages of germination of three lots of Goens wheat from seed untreated or treated with steam, as specified, following a 4-hour soak in cold water, at Arlington Experiment Farm in 1920*

Treatment of the seed			Percentage of germination			
Kind and temperature	Duration		Lot 1	Lot 4	Lot 13	Average
	Hours	Minutes				
Untreated			90.1	88.8	87.7	88.9
Treated:						
At 47° C.	1		92.6	85.1	87.0	88.2
	1	30	88.8	87.2	79.6	85.2
	2		81.5	90.7	74.0	82.1
	2	30	81.5	85.1	85.1	83.9
	3		87.0	83.3	81.5	83.9
	3	30	77.7	72.2	75.9	75.3
	4		87.0	77.7	74.0	79.6
	4	30	67.2	64.8	64.8	65.6
	5		68.5	66.6	70.3	68.5
At 48° C.	1		74.0	75.9	77.7	75.9
	1	30	64.8	74.0	66.6	68.5
	2		62.9	61.1	53.7	59.2
	2	30	46.2	44.4	64.8	51.8
		45	85.1	70.3	83.3	79.6
At 49° C.	1		70.3	77.7	74.0	74.0
	1	30	62.9	64.8	59.0	62.2

EFFECTS OF STEAM TREATMENTS ON GERMINATION, EMERGENCE OF SEEDLINGS, SMUT CONTROL, AND YIELD

Steam treatments were studied first in relation to germination. Three lots of Goens wheat (Nos. 1, 4, and 13) grown in 1920 were employed. Samples of each of the lots were treated during the period from November 9 to 12, 1920, at the temperatures and during the time periods specified in Table 11. The treated wheat was left

to dry one week at room temperature. Then 100 untreated seeds and 100 seeds from each of the treatments of each lot were sown in soil in greenhouse flats. Germination counts were made one month after sowing. The results are presented in Table 11.

Table 11 shows that germination was not reduced materially by steam treatment at 47° C. for three hours or less, but at 48 and 49° C. considerable injury occurred when the duration of treatment was one hour or more. It will be noted also that with decrease in temperature corresponding increases in the duration of treatment caused less injury to the seeds. For this reason treatments at lower temperatures seem preferable where large quantities of seed wheat are involved, as in steam treatments. The larger number of bushels treated would reduce the cost of additional time of treatment per bushel to a negligible amount.

In 1921–22 steam treatments were applied at 46°, 47°, and 48° C., and the effects on germination, rate of emergence, yield, and control of loose smut and bunt were studied. Two lots of Goens wheat (Nos. 16 and 17) grown in 1921 were used. Samples of each of the lots were inoculated with a small quantity of bunt spores and treated during the period from October 10 to 12, 1921, at the temperatures and during the time periods specified in Table 12. The treated wheat was left to dry one week at room temperature, when it was packeted and used, as described below. For the study of germination and rate of emergence 100 untreated seeds and 100 seeds from each of the treatments of each lot were sown in soil in greenhouse flats on November 12, 1921. From the date of emergence of the first seedling daily records of the number of seedlings which had emerged were taken for one month.

TABLE 12.—*Average rates of emergence of seedlings from two lots of Goens wheat from seed untreated or treated with steam, as specified, following a 4-hour soak in cold water, at Arlington Experiment Farm in 1921*

Treatment of the seed			Percentage of emergence after the following numbers of days												Days required for completion of emergence
Kind and temperature	Duration		5	6	7	8	9	10	11	12	13	14	15	30	
	Hours	Minutes													
Untreated			40	67	83	85	85	85	85	85	85	85	85	85	8
Treated:															
At 46° C.	1	30	54	80	81	85	87	88	88	88	88	88	88	88	10
	2		57	75	88	92	92	93	93	93	93	93	93	93	10
	2	30	37	69	83	86	86	88	89	89	89	89	89	89	11
	3		34	68	85	93	94	96	96	96	97	97	97	97	13
	3	30	31	62	77	81	83	85	86	86	87	88	88	88	14
	4		28	53	67	76	81	84	87	89	89	89	89	89	12
	4	30	16	41	67	72	76	79	80	81	83	83	84	84	14
	5		12	41	62	72	73	74	78	80	81	82	82	82	14
At 47° C.	1		37	64	82	89	91	91	92	93	93	93	93	93	12
	1	30	28	51	71	82	82	83	83	83	84	84	84	84	13
	2		27	33	62	70	77	79	79	79	82	84	84	84	14
	2	30	11	31	57	67	70	73	77	80	80	81	81	81	14
	3		3	11	36	61	65	67	70	72	75	76	78	78	15
At 48° C.		30	69	84	90	91	92	93	93	93	93	93	93	93	10
		45	62	78	82	85	87	88	89	89	89	89	89	89	11
	1		67	79	89	90	93	93	95	95	95	95	95	95	11

Table 12 shows that none of the treatments caused appreciable reduction in the final percentage of emergence, but all of them re-

tarded emergence. In general, the degree of retardation was intensified with increases in duration of treatment at a given temperature and with increases in temperature with a given duration of treatment, as was also noted in the germination of seed treated with hot water. Many of the seedlings which required over 10 days to emerge were small and spindling.

In an experiment to determine the effects of steam treatments on the control of loose smut and bunt and on yield, untreated and treated seed of the same two lots of Goens wheat (Nos. 16 and 17) were used. On October 28, 1921, untreated seed and seed from each of the treatments of each lot were sown on the Arlington Experiment Farm, Rosslyn, Va., in rod rows in 10 replications. The rows were spaced 1 foot apart, and the rate of seeding was 6 pecks per acre. The results are presented in Table 13. A zero in the smut columns indicates that no smut was found in a complete examination of the plants in all 10 rows. When less than 1 per cent of smut was present it is shown by T (trace), and the total number of smutted heads found in an examination of all 10 rows appears in parentheses. The other data represent the average percentages of smut determined by making a count of 200 heads in each of five rows.

TABLE 13.—*Percentages of infection of loose smut and bunt, and individual and average yields of Goens wheat from two lots of seed untreated or treated with steam, as specified, following a 4-hour soak in cold water and grown at Arlington Experiment Farm in 1922*

[T=trace (less than 1 per cent). The figures in parentheses show the number of smutted heads found in all 10 of the rod rows]

Treatment of the seed			Percentage of bunt		Percentage of loose smut		Acre yield (bushels		
Kind and temperature	Duration		Lot 16	Lot 17	Lot 16	Lot 17	Lot 16	Lot 17	Average
	Hours	Minutes							
Untreated			1.0	6.5	4.5	6.1	24.9	24.1	24.5
Treated:									
At 46° C.	1	30	T (9)	3.8	T (5)	T (5)	24.2	23.6	23.9
	2		1.0	3.3	0	T (1)	22.9	23.2	23.1
	2	30	T (2)	2.2	0	0	24.2	25.6	24.9
	3		T (8)	2.0	0	0	25.3	26.8	26.1
	3	30	T (3)	T (6)	0	0	23.5	22.9	23.2
	4		T (3)	T (8)	0	0	24.5	24.3	24.4
	4	30	0	T (3)	0	0	23.9	23.2	23.6
	5		T (1)	T (2)	0	0	22.2	23.5	22.9
At 47° C.	1		T (7)	2.2	0	T (8)	25.4	24.5	25.0
	1	30	0	2.2	0	0	24.3	23.3	23.8
	2		T (3)	1.5	0	0	24.4	23.3	23.9
	2	30	0	T (7)	0	0	24.0	25.2	24.6
	3		T (4)	T (2)	0	0	21.5	21.1	21.3
At 48° C.		30	1.0	1.5	T (13)	T (6)	25.9	26.3	26.1
		45	T (6)	1.3	T (1)	T (2)	23.5	23.4	23.5
	1		T (4)	2.8	0	T (1)	22.7	24.2	23.5

Table 13 shows that 10 of the 16 treatments completely controlled loose smut. None of the treatments eliminated bunt, but those at 46° C. for more than three hours and at 47° C. for more than two hours reduced it to a trace. Two of the treatments, one at 46° C. for five hours, the other at 47° C. for three hours, reduced the yield slightly in excess of 1.5 bushels per acre. Nine of the treatments reduced the yield less than 1.5 bushels per acre, whereas five of the

treatments slightly increased the yield. The treatment at 47° C. for 2 hours and 30 minutes was one of the most satisfactory. Plants from the seed thus treated contained no loose smut, only a trace of bunt, and yielded slightly more than the plants from untreated seed.

In regard to the application of steam treatments of seed wheat in large commercial driers, it may be noted that some engineering problems would be encountered—the soaking of 500 bushels of wheat, for example, and its transfer to the drier. In the movement of wheat in mills gravity flow plays an important rôle. Wheat which has been presoaked for four hours, however, will not flow.

DISCUSSION

In experiments dealing with hot-water treatments reported here and in experiments with the modified hot-water treatment previously reported by the writer (*15*), indications of stimulation to germination or yield resulting from treatment have never been obtained. On the contrary, treated machine-threshed seed invariably germinated lower than untreated seed, the seedlings emerged more slowly, the yield was reduced except when the rate of seeding of the treated grain was increased, and the plants from untreated seed contained a relatively high percentage of loose smut.

In a consideration of the value of treatment, however, attention must also be given to the fact that benefits other than control of loose smut may accrue in the plants grown directly from treated seed. For example, Gregory (*5*) notes that in the State of Indiana "smut-free areas are being established in which it is hoped that wheat can be maintained free from loose smut for several years" and that "it has been demonstrated in Knox and Shelby Counties that a widespread use of treated seed will greatly reduce the dangers of the spread of the smut. In Knox County it was found last summer that wheat which had been treated last year had no smut in it; that which was one year from treatment had no smut; two years from treatment there was one-quarter per cent; and three years from treatment 2 per cent, while in the untreated fields there was an average of 8 per cent." It seems that the value of treatment should be greatly increased in this system by reducing the need and use of treatment to a minimum and by giving full play to the beneficial effects accruing from treatment. Apparently no data are available, however, showing the net gain or loss which eventually results when the effects of treatment are considered on subsequent crops sown in smutty or in so-called smut-free areas.

SUMMARY AND CONCLUSIONS

The modified hot-water treatment of seed wheat (described on p. 1) for the control of loose smut is open to three principal objections: (1) It is difficult to apply, (2) it soaks the seed, and (3) in the presence of broken seed coats it is very injurious to germination. Experience gained at home and abroad seems to show that, in communities where loose smut in wheat is a factor of considerable economic importance, properly equipped cooperative or community seed-treatment plants afford the best means to facilitate the application of treatment and to popularize control. Studies therefore were made (1) of single bath hot-water treatments to devise, if possible, a method less injurious to germination, and (2) of steam

treatments to determine the possibility of using the commercial grain drier in connection with the steam treatment of grain, followed by drying the grain with warm air.

Single-bath hot-water treatments were applied by immersing wheat in half-filled sacks in water held at a constant temperature during definite periods, the duration of treatment extending from 30 minutes to 4 hours and the temperatures from 46° to 51° C.

A number of the single-bath treatments completely controlled loose smut and effectively controlled bunt, but the treatments at 48° C. for 1 hour and 50 minutes and at 49° C. for 1 hour and 35 minutes gave the best results. Although the resulting germination was somewhat poorer than that of the untreated seeds, these treatments did not seriously reduce or retard germination, and they reduced yield less and required a shorter period of application than any of the other treatments which approximated them in general effectiveness.

Wheat treated at 48° C. for 1 hour and 50 minutes or at 49° C. for 1 hour and 35 minutes in comparison with untreated seed showed poorer germination, the seedlings emerged more slowly, the plants yielded slightly less, and the yield was more adversely affected by unfavorable soil conditions.

Wheat treated at 48° C. for 1 hour and 50 minutes or at 49° for 1 hour and 35 minutes, in comparison with wheat treated by the modified hot-water method invariably germinated better, the seedlings emerged more rapidly, the plants yielded considerably more, and the yield was not so adversely affected by unfavorable soil conditions. In general, therefore, these single-bath treatments produced notably better results than the modified treatment.

As in the case of the modified method, the effects of the single-bath method on germination were dependent on the physical condition of the seed coats. Hand-threshed seed with unbroken coats suffered some retardation, but little, if any, reduction in germination. When the coats of hand-threshed seed were broken at definite locations over the endosperm the treatment reduced germination considerably, and when the coats were broken over the embryo the treatment reduced germination very markedly. The germination of wheat with coats broken over the embryo or endosperm was reduced less by the single-bath method, however, than by the modified method.

When the seeding rate of treated seed was increased so that the quantity of viable seed sown was the same as that of untreated wheat, plants from the latter outyielded plants from treated seed. The results seem to indicate that the injurious effects of hot-water treatments, especially the modified treatment, are not confined to germination, but may extend into later stages of plant growth.

There were no appreciable differences in the bushel weight of wheat grown from untreated seed and from seed treated with hot water by the modified or the single-bath method.

With a simplifying of the application of single-bath hot-water treatments in view, experiments were conducted to determine whether agitation of the hot water could be substituted for agitation of the sacks in the water. When cotton and burlap sacks half filled with wheat and tied at the top were placed on slatted shelves suspended in mechanically agitated water at 48° C., the period required for the

penetration of heat to the center of the mass of wheat in a cotton sack was approximately four times that required for wheat in a burlap sack.

Rapid penetration, even through burlap sacks, was obtained only by strong mechanical agitation of the water and when the sacks were placed in close proximity to the source of agitation.

Reduction in the amount of agitation or removal of the sacks a short distance from the source of agitation greatly decreased the rate of penetration. These facts indicate that agitation of the sacks no doubt would be necessary, at least for a short time at the beginning of treatment until the temperature of the mass of sacked wheat reached the temperature of the treatment bath.

Two kinds of machines may be had which could be used in combination to treat large quantities of wheat by the single-bath method and to dry the wheat so treated. Under our present system of seed treatment, however, the use of machines of these kinds would be impracticable, because they would be used only for a short period previous to sowing time and their efficiency would be greatly reduced by the need of treating many small seed lots and of keeping each of the lots separate.

Single-bath treatments could not be employed at central or community seed-treatment plants as usually equipped without material reduction in the daily output of the plants. The successful adoption of these treatments therefore seems dependent upon the development of practical methods and machinery which will facilitate their application.

Steam treatments were applied in an upright grain drier with a capacity of 2 bushels of wheat. Except in size, this machine is similar to the standard driers.

With this machine the following results were obtained: (1) A saturated recirculating atmosphere was maintained in the drier at temperatures suitable for the treatment of seed wheat (46° to 49° C.); (2) the temperatures were maintained with but slight variation; (3) the only change necessary to obtain these conditions was the attachment of a return pipe to the outlet of the drier to provide for recirculation of the saturated air; (4) the seed was soaked for four hours before treatment with steam at a temperature of 46° to 48° C. for periods of time ranging from one to five hours; and (5) in the experiments of a single year some of the treatments effectively controlled both loose smut and bunt without material injury to germination or reduction in yield. In some instances the yield of plants from treated seed was greater than that from untreated smutted seed.

The application of steam treatments to large quantities of wheat would involve some difficulties not encountered in the foregoing experiments.

The single-bath hot-water and steam treatments were studied only from the viewpoint of application at cooperative or community seed-treatment plants or at establishments handling large quantities of seed wheat. The application of these treatments involves the maintenance of constant temperatures for relatively long periods of time, special equipment, and other factors which make them hardly practicable of application by the individual farmer.

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